

MEDICAL TECHNOLOGY ADVANCES FROM SPACE RESEARCH

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Abstract

A number of medically oriented research and hardware development programs have been sponsored by NASA for support of manned space flights. Some of these medical programs for manned flights resulted in the development of technology which advanced the state of the art and, when applied to earthbound medical tasks, truly represent medical benefits from space research. These advances include computer techniques to remove irrelevant details from medical X-rays, sight-operated switches to assist patients who cannot move their extremities, wireless cardiac monitoring for intensive care units, and many others.

Currently there are several NASA-sponsored medical research and development programs which have significant potential for ground use as well as space application. The integrated medical laboratory, now under development by NASA, incorporates many advanced features, such as digital biotelemetry systems, automatic visual field mapping equipment, sponge electrode caps for clinical electroencephalograms, and advanced respiratory analysis equipment. A preliminary flight design has been completed and a functional testbed unit is contemplated for the mid-seventies. Modules of this integrated medical laboratory may be useful in ground-based remote area and regional health care facilities as well as on long-duration space missions.

Introduction

The National Aeronautics and Space Administration has had a number of medical development programs in support of space flights. Some of these medical development programs have produced technology which has been applied to ground-based medical use.

These space-oriented medical programs were started prior to the Mercury flights and have continued to the present time.

Background

The Mercury program started with Alan Shepard's 15-min suborbital flight and ended with Gordon Cooper's 34-hour 20-min flight.

The Gemini program paved the way for man's first flight to the moon. The first Gemini flight was March 1965 and the last was November 1966. The first manned Apollo flight was in September 1968. The first manned landing on the moon by Neil Armstrong and Buzz Aldrin was in July 1969. Perhaps in the distant future, interplanetary flights lasting as long as 2 years or more will be flown. Skylab is scheduled to be the first of the long-duration flights. Three men will live in an orbital workshop for periods lasting as long as 56 days.

The Shuttle and Space Station complexes are currently planned for the late seventies and early eighties, and the Space Base during the eighties. Beyond space bases there may be manned planetary missions.

The early NASA biomedical systems were used in two ways: to monitor vital physiological parameters such as heart rate, blood pressure, respiratory rate, electroencephalogram, and body temperature; and to conduct medical experiments to answer specific scientific questions. The vital physiologic functions were mentioned on all of the manned space flights.

Changes in the cardiovascular system were studied on the Gemini VII mission, which was the longest of the Gemini flights. Gemini VII indicated it was possible to fly an Apollo mission to the moon without expecting any serious physiological degradation in the crewmen.

The biomedical systems used during Mercury, Gemini, and Apollo answered many questions. The ability of man to exist safely in space flight for 14 days was proved. Man can probably live and work safely during extended-duration missions lasting 30 days.

Physiological studies, such as lower body negative pressure experiments, were performed before and after missions. Extensive pre- and post-flight testing was accomplished for all NASA manned space flights.

Bioinstrumentation used in space flights was developed to meet the rigorous requirements of size, weight, and power consumption of the spacecraft. In some cases, complete new bioinstrumentation systems were necessary to accomplish a specific physiological study. Inflight recorders, blood pressure apparatus, and biopotential signal conditions were assembled as prototypes and subjected to tests that lead to flight qualification.

Physiological data were telemetered to ground stations or recorded for playback. Physiological data were recorded in flight with the crewman at rest, as well as during exercise periods, for blood pressure, electrocardiogram, and respiration parameters.

The Skylab program should provide the medical scientist with the necessary data to assess the effect of the spaceflight environment on several of man's physiological systems for periods of time lasting as long as 56 days. The Skylab orbital workshop will be launched unmanned into earth orbit. Three crewmen who will inhabit the workshop for periods of time as long as 28 days will be launched in an Apollo Command and Service Module. Two subsequent three-man crews are scheduled to inhabit the Skylab workshop for periods as long as 56 days. Medical equipment to be flown on these flights will permit the measurement of physiological parameters.

Major areas of medical study in the Skylab program include the cardiovascular responses to exposure of the crewmen to lower body negative pressure; respiratory, cardiovascular, and metabolic responses to a programmed workload on the bicycle ergometer; and vestibular responses to rotation and attitude changes in a rotating litter chair [1].

Exposure of the crewman's legs and lower torso to reduced atmospheric pressure, in some respects, duplicates the pooling of blood in the lower extremities while standing in 1 g. This passive cardiovascular stress will allow the medical scientist to determine, to some extent, the effects of the 0-g environment on the crewman's cardiovascular status. Repeated regular lower body negative pressure (LBNP) exposure may serve, as a countermeasure, to keep the cardiovascular system in good condition for return to 1 g.

A bicycle with a programmable workload was developed for Skylab. The ergometer workload is automatically adjusted to maintain a preset heart rate. During the time the crewman is on the bicycle his physiological responses are recorded onboard the workshop and may be transmitted to the ground in real time or at a later time for analysis. In addition to providing valuable physiological data, the bicycle ergometer will also function as a 0-g deconditioning countermeasure.

The Skylab rotating litter chair will impart small gravitational forces to the vestibular canals in the inner ear. The vestibular apparatus in man is normally subjected to 1 g and helps man to determine his position relative to the earth, but in 0 g it may be more sensitive to gravitational disturbances.

The central nervous system's functions will be monitored during sleep by the Skylab sleep cap, electroencephalogram signal conditioner, and the Frost sleep analyzer.

The Inflight Medical Support System (IMSS) is to provide, in the Skylab workshop, a limited inflight medical diagnostic and treatment capability for routine and emergency medical care of an outpatient nature [1]. The IMSS consists of two basic groups of equipment, diagnostic and therapeutic. For diagnostic purposes, the IMSS is supplied with the standard clinical instruments such as stethoscopes, sphygmomanometers, thermometers, etc. Additionally, medical laboratory equipment is provided that will allow blood analysis, urinalysis, and microbiological examinations. For therapeutic purposes, the IMSS is supplied with a wide selection of drugs. It is also outfitted with a minor surgery pack for the care of minor lacerations.

Perhaps in the distant future, interplanetary flights will last as long as 2 or more years. How will man's physiological systems adapt to prolonged periods of weightlessness of 1 yr or more? Will man's behavior change; and if so, how will the changes affect his performance? Are there any countermeasures which might be employed to prevent, correct, or delay deconditioning?

The Skylab missions should serve much the same scientific purposes for these extended missions as the Gemini VII flight served for the Apollo program. However, the bioinstrumentation systems and medical experiments on Skylab will not be adequate to answer all of the significant physiological

questions about extended-duration missions. Thus, the Skylab medical experiments may only raise additional questions.

The extended-duration missions will require more comprehensive capabilities in the areas of medical research and clinical medicine. Onboard laboratory facilities will be required to measure such diverse factors as lung volumes, lung diffusion capacity, urine and blood ion content, red blood cell fragility, and sensory perception.

As crew size increases from 3 men, on the Skylab missions, to 12 men, as proposed for early space stations, the onboard clinical medicine support for the crew must be expanded. The Skylab IMSS will be adequate to provide support for 3 men in space for up to 56 days, but not for 12 men for 1 yr or more.

As a result of these considerations, NASA is developing the Integrated Medical and Behavioral Laboratory Measurement System (IMBLMS).

The IMBLMS will provide for onboard medical support of the crew and medical research. The medical support system will provide the capability for diagnosis and treatment of illnesses and injuries. The medical research system will provide a core laboratory that will allow the life scientists to conduct a comprehensive series of physiological and clinical measurements in flight. Data for display, storage, playback, and transmission to the ground will be processed by IMBLMS.

Flexibility in the IMBLMS design will permit changes in capability and equipment integration from mission to mission. Each major IMBLMS component must be capable of being used individually or in combination to perform many different measurements. By the use of a flexible design approach, IMBLMS will not only be suitable for use in early extended space flights, but will also have the potential to accommodate new measurements developed in the future to meet the changing mission requirements.

In 1968, NASA elected to design, build, and test functional breadboards of the IMBLMS to demonstrate flight-applicable techniques and gain information needed to develop requirements for flight

hardware and software. At this stage of development it was premature to include any flight packaging. The information collected during the production and testing of the functional breadboards was applied to the preliminary flight design which followed.

The functional breadboard systems (FBBs) were delivered to the Manned Spacecraft Center (MSC) in January 1970, and were installed and operational in February 1970. Since that time the FBBs have undergone extensive testing and analysis. The testing was intended to establish the value of the techniques under study; however, this testing also demonstrated that some of the techniques were inadequate, too complex or time consuming to be included in the flight designs [2]. Alternative techniques are being sought for those measurements considered essential to the flight system, but were obviously inadequate techniques in the breadboards.

The Integrated Medical and Behavioral Laboratory Measurement System is an advanced medical system which may have applications on earth as well as in space.

Benefits

With this brief overview of NASA's medical development programs, it is easier to grasp the potential for future medical technology applications from space research as well as understand those which have already occurred. A partial listing of NASA's technology, which has been applied to ground-based medical use, includes infant breathing monitor, X-ray enhancement, pressure transducer for cardiac catheters, special biopotential electrodes, and an artificial heart controller [3].

Infants, comatose children, or adult patients sometimes require surgical implantation of a tracheotomy tube in the windpipe. If the tube is clogged, cutting off breathing, brain damage or death can result within from 2 to 4 min. Ordinarily a full-time nurse is required to visually check the tube and take immediate corrective action. Integrated circuitry, designed and fabricated for aerospace use, was incorporated in a small device to monitor the temperature of air passing through the tube and actuate an audible or visual alarm within 10 sec of any change. The signal can be given at a nurse's

station, or in another room, if the patient is at home. Thus the patient's care is improved and facilitated.

The breathing monitor, based on an automatic air surveillance system developed by NASA scientists, contains a temperature sensor/FM transmitter attached directly to the tracheotomy tube to allow the inspired and expired air to flow directly over a thermistor temperature sensor.

Techniques for the correction of photometric, geometric, and frequency response distortions in television pictures received from a spacecraft have now been applied to the study of medical X-rays. The X-ray picture is first converted into digital form by means of a cathode-ray device that scans the film on a line-by-line basis and converts each point of the picture into a number proportional to the film's optical density. Each sample (typically 500 000 samples for a 1-in.² transparency) is recorded on a magnetic tape which is subsequently fed into a computer.

Further computer enhancement is achieved by a two-dimensional digital filter to modify the frequency spectrum of the picture. Filtering is used to restore high-frequency losses of fine detail resulting from the use of fluorescent X-ray intensifying screens.

Another computer processing method involves image subtraction. Two pictures depicting the same area of the body, perhaps taken at different times, are subtracted from one another on a point-by-point basis. The resultant difference picture will emphasize changes, such as tumor growth.

The operational principles of a sensitive micro-meteorite detector have been used to develop a muscle accelerometer. Change in acceleration of this instrument causes the deflection of a sensitive piezoelectric crystal. The accelerometer is attached to the patient to provide an accurate record of very slight muscle reflexes and tremors.

Use of the instrument is proving valuable in current studies of reflexes and tremors associated with neurological disorders. Previous studies based on motion pictures and direct visual observation were unsatisfactory in obtaining accurate quantitative data. For example, accurate determination of the time cycle of arm movements previously

required tedious examination of many motion picture frames, while low-amplitude tremors remained undetected.

An astronaut's space helmet provided a development model for research on oxygen consumption of children at a university medical center. The children, both normal individuals and those with heart defects, experienced difficulties and discomfort with the conventional rubber mouthpiece used for collection of exhaled breath. During heavy breathing, the comparatively high resistance to the flow of gas increased the workload on the subject. The extra effort required additional oxygen which impaired the accuracy of the data on oxygen consumption.

A solution was offered by a modified NASA space helmet which was equipped with an air inlet and outlet and a rubber seal around the neck. A suction pump was provided to continuously circulate fresh air through the helmet, picking up the exhaled breath and drawing the combined fresh air and exhaled breath into an oxygen analyzer.

When a pediatric cardiologist experienced difficulties in obtaining accurate electrocardiograms from children during exercise, he adopted a technique for conducting medical research on test pilots. The use of an electrode sprayed onto the body of an astronaut had improved the accuracy of electrocardiograms by reducing variations in the electrical contacts produced by movements of standard metal-plate electrodes.

A modified commercial spray gun is used to spray an electrically conductive mixture of a commercial household cement, silver powder, and acetone, as well as air-drying the deposit at an air pressure of about 20 psi. The mixture is simultaneously sprayed over the end of the lead wire from the electrocardiogram and a half-dollar area of skin, previously cleaned and coated with an electrode jelly. The application of the electrodes does not require removal of hair, and the thin, flexible layer is quickly removed with acetone.

Transducers originally designed for pressure survey probes in wind tunnels and for telemetry of pressure data from small free-flight models have been adapted for measurement of intravascular pressures in humans. A miniature diaphragm-type capacitance transducer was designed to be fitted on the end of a cardiac catheter and inserted by

percutaneous techniques, using standard needles that are routinely used for venous or arterial punctures.

The two capacitor plates, used to sense pressure, consist of a cell diaphragm and a film of platinum fired onto a glass core separated by an air gap. The central metal tube in the cell provides an electrical connection to the platinum film and serves for passage of reference pressure to the capacitor air space. The electronic system, connected to the catheter for sensing pressure, consists of a capacitance bridge network excited by a crystal oscillator, a low noise transistor amplifier, and a demodulator for producing an analog signal or a CRT display.

A major problem in teaching a handicapped person to walk is to help him make an easy transition to his old environment. There are many severely handicapped persons who, after a prolonged immobile period in bed, experience great difficulty in adjusting to walking with crutches or sitting up in a wheelchair. In addition, there is the problem of a patient learning to walk with artificial legs under normal weight/gravity conditions. A definite need was found for a partial support system to reduce the physical workload imposed on such a patient during this training and transition period. Water-bath support systems being used were inconvenient and hampered limb motion. A lunar-gravity simulator was found adaptable to this problem. The device can be adjusted for any degree of support required, and the sling is more comfortable than a harness.

One of the concerns in using radiation therapy for cancer is preventing damage to the surrounding healthy tissue. Radiation therapists needed to measure the radiation level absorbed around the cancerous area in order to either control the treatment with improved precision, or to determine the position of administered radioisotopes rapidly and accurately. A miniature radiation-dosimeter probe was made available for such use. The probe, approximately the size of a clinical thermometer, is based on solid-state and semiconductor phenomena.

A list of representative medical technology, which is developed but not generally applied, includes such items as dry stained slides. These prestained slides employ a specific mixture of dyes which have been predeposited as a thin, dry film on the surface of a standard microscope slide. A hinged coverslip, in conjunction with the label, is also attached to

make a complete slide assembly so that the following routine blood tests can be conveniently performed on a single slide: platelet estimation, reticulocyte count, and white blood cell differential count. This technique reverses the procedure normally practiced with traditional bloodstains. The blood sample is deposited first with these, followed by the application of the stain. Elimination of the necessity for manipulating basic/volatile stains by the technician, with concomitant increase in time, allows preparation of the blood smear in essentially one easy operation. The prestained slide technique also permits the performance of these clinical tests on blood uncontaminated with heparin or other anticoagulants, which may have an effect on cellular morphology.

Slight differences in staining characteristics will be noted as the result of the new dye mixture employed. These differences are easily overcome with minimal observation of the preparations through the microscope; experience has shown that personnel familiar with the Wright's stain technique are able to adjust to the prestained slide characteristics with only 10 or 15 min of practice.

The National Institutes of Health and National Institute of Cancer are now evaluating these dry stained slides with pathological blood samples for possible application in cancer research.

The automatic blood pressure measurement system developed for Skylab has several unique features which permit an accurate measurement of blood pressure even during exercise.

Dry silver chloride electrodes were developed for manned testing, which have small impedance balancing amplifiers embedded in the electrode.

A three-dimensional tremor and reaction detector has been developed and is now being tested with normal subjects, as well as with patients who have neurological disorders.

The mass spectrometer developed for the Skylab metabolic analyzer is being configured to measure oxygen consumption and carbon dioxide production by patients in intensive care units as well as to measure blood gas concentration in near real time.

The Frost analyzer, which is to be used on Skylab as a sleep monitor, may be applicable to operating rooms to monitor the level of anesthesia.

Initial studies of this application of the sleep monitor are now underway in the Texas Medical Center.

There are many items of medical hardware, which have been breadboarded for ground-based study, that were designed but not fabricated for use in space. A few representative items of this type of development hardware include an automatic peripheral visual-field mapping system. Normally visual fields are mapped in a manual mode which is time consuming and often not as accurate as might be desired. The NASA system operates much like an automatic hearing tester (if you hear a sound, push the button until the sound goes away), only for the vision system the test involves light instead of sound.

A disposable sponge electrode cap in the international electrode configuration for the electroencephalogram was developed and tested on a limited basis. The clinical electroencephalograph cap seems to have considerable potential for ground-based use.

A digital biobelt is being developed which has several advantages over present body-worn systems. All components will be microminiaturized. Digital data may be brought off the man by use of very small coaxial cables or via an RF link. The biobelt incorporates optical couplers and advanced current-limiting devices for improved safety.

There are a number of medical research and development programs in the feasibility stage that have considerable potential for space and ground-based applications. The Microbial Ecological Monitoring System (MEMS) is a passive immune agglutination test for rapid viral identification. Small Latex beads, 2.0 to 0.2 μ m in size, are coated with specific antibodies which have been developed in animals exposed to the viruses. These antibody-coated beads clump or agglutinate when exposed to the specific virus antigen to which they are sensitive. The organisms which have been tested to date are myxovirus, adenovirus, herpesvirus, echovirus, coxsackie virus, and mycoplasma. The advantages for space application are the same as on the ground and include rapid screening (a few minutes versus the 2 weeks at the present). The test is highly specific, may be accomplished by a technician, and should cost less than the present tissue-culture techniques.

The objective of the three-dimensional vector cardiograph presentation is to test and verify a new semiautomatic, three-dimensional display of a vectorcardiogram in a clinical setting. The system is

designed as a display capable of presenting a vectorcardiogram (VCG) in three-dimensional perspective. The system is based on the Data General NOVA machine; data are displayed on an oscilloscope and on an X-Y plotter. Projections of the individual VCG complexes on the standard anatomical axes or on rotated axes are provided. Horizontal, frontal, and sagittal plane displays are available for comparison with the three-dimensional VCG display.

This system, if successful, will provide a powerful tool for interpretation of VCGs and must be tested in a clinical setting with both normal and abnormal data to verify its function and capabilities. The method of presentation should be valuable to spaceflight research and ground-based medicine.

Initial studies conducted by MSC using stereophotogrammetry for determining body shapes in three dimensions have shown a high probability of developing into a highly accurate, space-compatible technique for measuring body volume.

The fact that organic structures are inherently three dimensional opens up a wide range of possibilities from microscopic studies to investigations of whole body form. A varied research embracing such areas as spinal deformities, prosthetic design, body and limb plethysmography, tumor detection and growth is being conducted at the Texas Institute for Rehabilitation and Research, Baylor College of Medicine, MSC, and other institutions. The need for an accurate and practicable means of measuring body surface areas, volumes, volume distribution curves, deformities, changes in form, and related parameters of intact organisms or their parts would seem to assure a bright future for stereometrics in the biomedical sciences and clinical practice.

A miniature analytical laboratory system designed to operate on spaceships for monitoring the health of astronauts is being developed at Oak Ridge National Laboratory. The minisystem is called the gravity-zero analyzer (G0 analyzer) because it will be designed to operate in the weightlessness of outer space. The G0 analyzer will utilize the technology developed under Oak Ridge National Laboratory's basic, fast analyzer work at the laboratory's Molecular Anatomy program.

The G0 analyzer will be designed to permit astronauts to perform, quickly and automatically, up to 16 parallel chemical tests on 0.1 ml of plasma or serum based on calorimetric determinations. Results of the test will automatically be radioed to

ground control. One application of the system would be to analyze the blood and urine of an astronaut if he were to become severely ill during spaceflight. The system will consist of an enclosed rotor, drive mechanism, and stationary calorimeter for automatically dispensing the sample, mixing it with the necessary reagents, and measuring the optical density of each of the reaction mixtures during rotation. The G0 analyzer system will be useful in hospital emergency rooms and pediatricians' offices because it requires very little space, small samples, and is simple to operate.

In addition to its principal application on long-duration space missions, IMBLMS may have applications on earth. The IMBLMS program, established to provide systems capability for conducting biomedical experiments and clinical support, might offer some relief of the medical care problems that exist in the U.S. today.

There is widespread dissatisfaction with the delivery of health services in this country. The Department of Health, Education, and Welfare's report, "Report on the Health of the Nation's Health System," released in 1969, suggested that the U.S. faces a massive crisis in health care delivery. The problems of the health care system include: (1) inaccessibility of health services for many Americans, especially those who live in remote rural areas or in the inner city; (2) the U.S. health care establishment consists of government, industrial, and private interests who suffer from a lack of adequate means for communication and inadequate organization which adversely affects the availability, quality, efficiency, and cost of health services; (3) the cost of health services continues to rise above the financial capabilities of a large number of citizens; and (4) health personnel are in short supply, maldistributed, and specialized without regard to needs.

While the application of IMBLMS technology could obviously not cure all the ills of the U.S. health care establishment, it could be adapted for use on earth as a health services access system with the following features: (1) the use of an integrated medical, communications, and data management facility manned by physicians' assistants to provide points of entry into the health care establishment for people in medically deprived areas; (2) the provision for outpatient services on a local level coupled with the use of communications technology to provide the consultation support and supervision of the physician's assistant; (3) the

adequate disposition of medical and traumatic emergencies; (4) the use of appropriate combinations of fixed and mobile facilities to meet the varying needs dictated by population density, terrain, existing transportation systems, and socioeconomic characteristics of different areas; and (5) the use of information processing to relieve personnel of burdensome recordkeeping and administrative functions. These features permit efficient use of the physician's time and are essential for support and supervision of the physician's assistants.

Conceptually, a national network of health services units could be developed, although initially, a demonstration program would be a cost-effective method to establish the feasibility of the basic approach. The exact configuration of the demonstration program units would depend on the site or sites selected, but basically the system may be described as follows.

The remotely located field units would be supported by a control center located adjacent to a large hospital emergency facility. The control center would be in constant communication with the remotely located elements of the system. The local center would be a fixed facility located in a town without a medical clinic or hospital. The local center would offer outpatient and emergency health services and would serve as a relay point for communications with other more remotely located facilities. The mobile facility would be a scaled-down version of the local center which would be capable of offering health services to fewer people but has the advantage of being transportable over major roads, on a scheduled basis. The ambulances and hand-carried equipment would further extend the system to difficult-to-access areas.

The IMBLMS could be adapted very profitably for use on earth as a health services unit. Moreover, the IMBLMS program could offer other benefits to the general public, such as newly defined measurements, techniques, equipment, and ultimately, important tools for extending medical services.

Conclusion

Many medical research and development programs have been sponsored by NASA for space application. These efforts to develop techniques and equipment for application in space have resulted in medical benefits to the general public. Some

medical programs for manned flights resulted in the development of technology which advanced the state of the art and, when applied to earthbound medical tasks, truly represent medical benefits from space research.

Currently there are several NASA-sponsored medical research and development programs which have significant potential for ground use as well as space application. The integrated medical laboratory now under development by NASA incorporates many advanced features, such as digital biotelemetry systems, automatic visual field mapping equipment, sponge electrode caps for clinical electroencephalograms, and advanced respiratory analysis equipment. A preliminary flight design has been completed and a functional test bed unit is contemplated for the mid-seventies. Modules of this inte-

grated medical laboratory may be useful in ground-based remote area and regional health care facilities as well as on long-duration space missions.

References

1. Biomedical Experiments and Systems in Skylab. NASA, April 1971.
2. Integrated Medical and Behavioral Laboratory Measurement System Assessment, NAS 9-9456, A Final Report. The Boeing Company, December 21, 1970.
3. Medical Benefits from Space Research. Office of Technology Utilization, NASA, Washington, D. C., 1970.